DFUB 99/20
SLIM 99/1

SEARCH FOR "LIGHT" MAGNETIC MONOPOLES

The SLIM Collaboration

D. Bakari[1,4], S. Cecchini[1,a], H. Dekhissi[1,4], J. Derkaoui[1,4], G. Giacomelli[1], M. Giorgini[1], J. McDonald[3], G. Mandrioli[1], S. Manzoor[1,5], A. Margiotta[1], A. Marzari-Chiesa[2], J. Nogales[7], M. Ouchrif [1,4], L. Patrizii[1], J. Pinfold[3], V. Popa[1,6], O. Saavedra[2], P. Serra[1], M. Spurio[1], R. Ticona[7], V. Togo[1], A. Velarde[7], E. Vilela[1] and A. Zanini[2]

1. Dipar.to di Fisica dell'Università di Bologna and INFN, 40127 Bologna, Italy
2. Dipar.ti di Fisica Sperimentale e Generale dell'Università di Torino and INFN, 10125 Torino, Italy
3. Centre for Subatomic Research, Univ. of Alberta, Edmonton, Alberta T6G 2N4, Canada
4. Faculty of Sciences, University Mohamed I, B.P. 424, Oujda, Morocco
5. RPD, PINSTECH, P.O. Nilore, Islamabad, Pakistan
6. Institute for Space Sciences, 76900 Bucharest, Romania
7. Laboratorio de Fisica Cosmica de Chacaltaya,UMSA, La Paz, Bolivia
a Also Istituto TESRE/CNR, 40129 Bologna, Italy

Abstract

We propose to implement one passive nuclear track detector array of 400 m^2 at the Chacaltaya High Altitude Laboratory (5230 m a.s.l.). The main purposes of the experiment concern the searches for magnetic monopoles of relatively low masses at the Parker bound level, searches for low mass nuclearites, and searches for some supersymmetric dark matter candidates (Q-balls).

1. Introduction

The search for magnetic monopoles (MMs) in the penetrating cosmic radiation remains one of the main items of non-accelerator particle astrophysics.

Grand Unified Theories (GUT) of electroweak and strong interactions predict the existence of superheavy magnetic monopoles with masses larger than 10^{16} GeV [1]. They would have been produced at the end of the GUT epoch, at a mass scale $\sim 10^{14}$ GeV and the cosmic time of $\sim 10^{-34}$ s. Such monopoles cannot be produced with existing accelerators, nor with any foreseen for the future. The MACRO experiment is well suited for their study and is providing the best experimental limits [2].

Lower mass monopoles, proposed by many authors, require a phase transition in the early universe in which a semisimple gauge group yields a U(1) factor at a lower energy scale [1, 3]. MMs with masses around $10^6 \div 10^{10}$ GeV have been proposed [3-6]. A MM is a topological point defect; an undesirable large number of relatively light monopoles may be gotten rid of by means of higher dimensional topological defects (strings, walls) [3].

One of the recent interests in relatively low mass MMs is connected also with the possibility that relativistic MMs could be the source of the highest energy cosmic rays, with energies larger than 10^{20} eV [3-5]. For monopoles one knows possible acceleration mechanisms: since the basic magnetic charge should be very large, relatively light monopoles can be accelerated to relativistic velocities and to energies of the order of 10^{20} GeV in one coherent domain of the galactic magnetic field, or in the intergalactic field, or in many astrophysical sites, like in the magnetic field of Active Galactic Nuclei (AGN) and even of neutron stars. The next problem is how these monopoles can interact in the upper atmosphere and yield electromagnetic showers. This is for istance possible if a monopole forms a bound state with a proton (a dyonic system) which then may interact with a cross section typical of a relativistic hadron ($\sigma \geq 10^{-26}$ cm^2) [3-5]. Monopole masses of $10^6 \div 10^{10}$ GeV could be consistent with a flux at the Parker limit [3, 7].

We must also remember the possibility that MMs could be multiply charged, $g = 2g_D$, as in some SUSY theories, and $g = 3g_D$, as in some superstring models ($g_D = \hbar c/2e = 68.5\ e$ is the basic Dirac monopole charge) and that the basic charge could be $1/3\ e$ [8].

We propose a search for relatively light MMs with an array of 400 m^2 of passive nuclear track detectors deployed at the high altitude Chacaltaya lab (5230 m high above sea level). In $>$ 4 years of operation we should be able to reach a sensitivity at the level of the Parker bound, i.e. $\sim 10^{-15}$ cm^{-2} s^{-1} sr^{-1}. Byproducts of this MM search are the searches for relatively light nuclearites and Q-balls [9].

We recall that nuclearites (strangelets, strange quark matter) are nuggets of strange quark matter (aggregates of u, d, and s quarks in equal proportions); they could be the ground state of QCD and could be part of the cold dark matter, and could have typical galactic velocities $\beta \sim 10^{-3}$ [10].

Q-balls are supersymmetric coherent states of squarks, sleptons and Higgs fields, predicted by minimal supersymmetric generalizations of the Standard Model; they could be copiously produced in the early universe. Relic Q-balls are also candidates for the cold dark matter [11].

Since both nuclearites and charged Q-balls lose a large amount of energy for $\beta > 4 \times 10^{-5}$ they would be easily detectable with the proposed track-etch system.

An exposure at a high altitude laboratory would allow to search for MMs of lower masses, higher magnetic charges and lower velocities [12], see Figs. 1 and 2. The same holds for lighter nuclearites and Q-balls. For low mass nuclearites one

would reach a level of sensitivity more than one order of magnitude lower than any of the existing limits [13].

Fig. 3 shows the accessible region in the plane (mass, β) for nuclearites, at MACRO depth, at ground level (under 1000 g cm^{-2} of atmosphere), at the Chacaltaya altitude (540 g cm^{-2} of atmosphere) and at 20 km height assuming that the nuclearites have standard energy losses [10]. Lower mass nuclearites should be much more abundant than higher mass ones [14].

The high altitude exposure would allow detection of the above mentioned particles even if they had strong interaction cross sections which could prevent them from reaching the earth surface. From this point of view, it is important that the site be at the highest altitude. (On this point we have asked the opinions of several colleagues. In particular S. Glashow, J. Steinberger and A. De Rújula adviced us to search for the above mentioned objects at as high an altitude as possible.)

Experimental data obtained at the highest altitude laboratories suggest the existence of "Centauro events" and other exotic events. It has also been suggested that nuclearites with mass number of only few hundred could have nuclearite - air nuclei collisions at high altitudes in which the baryonic number of the nuclearite reduces by about the mass number of the target nucleus; this effect can be neglected for large mass nuclearites but it could seriously alter the energy loss of nuclearites with $A \sim 1000$ [15, 16]. The nuclearites would decrease in A in successive interactions with air nuclei until reaching some critical value, $A_{crit} \sim 320$, below which they disintegrate into nucleons. This mechanism could be tested at the highest altitude stations.

According to ref. [17] the initial mass number that a nuclearite should have at the entry in the atmosphere in order to reach the Chacaltaya altitude (540 g cm^{-2}) before disintegrating into normal baryons is $A \simeq 3000$, while to reach 450 g cm^{-2} altitude the initial mass should be about $A \simeq 1700$. Assuming that the abundance of nuclearites outside the atmosphere has the same A dependence as the abundance of elements in the Universe, the flux for $A \sim 1700$ would be about 100 times larger than the flux of nuclearites with $A \sim 3000$ [14].

We hope to instrument a small area (~ 2 m^2) with many layers of thin CR39 and other detectors; this also applies to a very small detector at higher altitudes.

2. Experimental method

In order to reach the goal of a sensitivity at the level of the Parker bound [7], one needs a surface detector of the least 400 m^2 and operation for at least four years. This detector also yields good limits on lighter nuclearites and Q-balls.

In order to achieve the best redundancy and "convincingness" the best detector should have redundant types of subdetectors, such as those presently used by the MACRO experiment at Gran Sasso: i) liquid scintillators for wave form

shape and time-of flight (ToF) informations, ii) tracking system to ensure single space track and single "time track" (for slow monopoles); iii) passive nuclear track detectors for space track and restricted energy loss analyses [18]. This solution would also yield byproducts on cosmic ray physics [19], but it would be expensive and complicated and it is not needed for the limited purposes of this proposal.

For the near future the simplest possibility is the use of several layers of different passive nuclear track detectors.

An exposure at a high altitude would effectively lower the monopole mass threshold and it would offer the new possibility of searching for any heavily ionizing object present in the cosmic radiation and which has a strong interaction cross section. This includes light MMs with attached p or nuclei, dyons, nuclearites and Q-balls; in fact one might consider this last point as one of the main reasons for such a search at high altitude.

The CR39 nuclear track detector allows to search for magnetic monopoles with one unit Dirac charge (g_D), for $\beta = v/c$ around 10^{-4} and for $\beta > 10^{-3}$, the whole β-range of $4 \times 10^{-5} < \beta < 1$ for MMs with $g \geq 2g_D$, for dyons, for nuclearites and for Q-balls.

We are presently making tests by exposing nuclear track detectors in Bologna and at the Chacaltaya mountain station, in order to study the effects of possible backgrounds and of possible climatic conditions.

3. Proposal

As already stated, we would like to implement passive nuclear track detectors of 400 m^2 at mountain altitude. The track-etch detectors could be organised in modules of 24 cm $\times$ 24 cm, each made of 3 layers of CR39, 3 layers of polycarbonate and of an aluminium absorber 1 mm thick; this module would be placed in an aluminized polyethilene bag filled with dry air. These bags reduce by about one order of magnitude the radon background. The CR39 is the main nuclear track detector; the polycarbonate has a higher threshold, and it is useful for high velocity monopoles and for nuclearites and Q-balls with $\beta > 10^{-4}$.

The best and least expensive CR39 is produced by the Intercast Europe Co. of Parma. We are in a position to obtain very good material, controlled continuously by us, and at the best possible price.

A program for the analysis of various types of polycarbonate (Lexan, Makrofol) is well under way. So far the best results were obtained with Makrofol (made by Bayer) of 0.5 mm thickness. There is no problem for the availability and cost either of Lexan or Makrofol.

Once exposed, CR39 and the Makrofol should be etched. Presently there are two etching facilities, one at Gran Sasso (the apparatus was built in Torino) and one in Bologna. The etching capacity of the Gran Sasso apparatus is about 26 m^2/month for "strong" etching of the first layer of CR39. The Bologna apparatus

is presently used for “normal” etching of the second CR39 layers; we are planning to use it also for strong etching to complement the Gran Sasso apparatus. The global etching rate would be 42 m^2/month At the quoted rate, we should be able to complete the etching of the MACRO nuclear track detector in about 2 years.

For the SLIM experiment we plan to etch small samples in the next few years, and start the main etching after the completion of the MACRO effort. We propose to etch about 150 m^2/year by using only the Bologna apparatus. The collaborators of the Pinstech Lab. could take care of the exposure, etching and analysis of about 100 m^2 of detector.

For the etching and for the analysis of the detector we may use the same methods presently used for MACRO; we shall also study other more authomated methods.

After exposure, the first sheet of each CR39 module is etched using a “strong etching” at 80°C in an 8N water solution of NaOH.

The etched CR39 is analyzed, first quickly using a simple method with a light source and a large lens and observing the CR39 foil in transparency; a more accurate analysis is later performed with a large field binocular microscope. At present, for the MACRO CR39, which has an average exposure time of 7 years, we find “candidates” in about 8% of the sheets. In these cases we etch the second CR39 foil of the interested module at 70°C in a 6N NaOH water solution (this is presently done in Bologna).

We need to make regular small exposures of CR39 and Makrofol to relativistic heavy ions in order to check the quality of the material used, its stability in time, the absence of fading effects, etc. [20, 21]. One main calibration test using Fe ions of 1 GeV/nucleon from the Brookhaven AGS is in progress.

5. The collaboration

The present collaboration involves groups from INFN and the Universities of Bologna and Torino in Italy, the University of Alberta in Canada, the University of Oujda in Morocco, the Pinstech Lab. in Islamabad, Pakistan, the Institute for Space Sciences of Bucharest, Romania, and the Laboratorio de Fisica Cosmica de Chacaltaya in La Paz, Bolivia. The main contributions from the Bucharest and Oujda groups are with personnel often stationed in Bologna in the context of bilateral agreements*.

7. Conclusions

We propose to install a nuclear track detector of 400 m^2 at the Chacaltaya high altitude lab. The detectors will be operated for at least 4 years. They will allow for a search for light monopoles and dyons at the level of the Parker bound,

that is at a flux of a 10^{-15} cm^{-2} s^{-1} sr^{-1}. A similar level of sensitivity will be obtained for relatively light nuclearites and for Q-balls.

Acknowledgements. We would like to acknowledge fruitful discussions with A. De Rújula, S. Glashow, J. Steinberger, and other colleagues.

*We thank the University of Bologna, the ICTP-TRIL program, Worldlab and FAI-INFN for providing fellowships and grants for non Italian scientists.

References

[1] Monopoles in Quantum Field Theory, N.S. Craige, P. Goddard, W. Nahm editors, World Scientific (1982); G. Giacomelli, Rivista del Nuovo Cimento 7 (1984) 1. Monopoles in Gauge Theories, Lecture Notes by N. Craige, G. Giacomelli, W. Nahm and Q. Shafi, World Scientific (1986).

[2] MACRO Collaboration (Search for magnetic monopoles with the MACRO detector) paper presented at the 26^{th} ICRC, Salt Lake City, Utah.

[3] E. Huguet and P. Peter (Bound states in monopoles: sources for UHECR?) hep-ph/9901370 (1999).

[4] T. J. Weiler and T. K. Kephart (Are we seeing magnetic monopole cosmic rays at $E > \sim 10^{20}$ eV?), Nucl. Phys. B. Proc. Suppl. 51 (1996) 218; T. W. Kephart and T. J. Weiler (Magnetic monopoles as the highest energy cosmic ray primaries), Astrop. Phys. 4 (1996) 217.

[5] C. O. Escobar and R. A. Vazquez (Are high energy cosmic rays monopoles?), Astrop. Phys. 10 (1999) 197.

[6] A. De Rújula (Effects of virtual monopoles), Nucl. Phys. B435 (1995) 257.

[7] M. S. Turner, E. M. Parker and T. T. Bogdan (Magnetic monopoles and the survival of galactic magnetic fields), Phys. Rev. D26 (1982) 1296.

[8] P. M. Sutcliffe (BPS monopoles), Int. Journal of Modern Physics A12 (1997) 4663; G. Lazarides et al. (Magnetic monopoles from superstring models), Phys. Rev. Lett. 58 (1987) 1707.

[9] M. Ambrosio et al. (Search for nuclearites with the MACRO detector at Gran Sasso), INFN/AE-97/20 (1997); in Proc. of the 25^{th} ICRC, Durban, vol. 7 (1997) 177.

[10] E. Witten, Phys. Rev. D30 (1984) 272; A. De Rújula and S. L. Glashow (Nuclearites-a novel form of cosmic radiation), Nature 312 (1984) 734.

[11] S. Coleman (Q-Balls), HUTP-85/A050 (1985); A. Kusenko et al. (Experimental signatures of supersymmetric dark-matter Q-balls), CERN-TH/97-346, hep-ph/9712212 (1997).

[12] J. Derkaoui et al. (Energy losses of magnetic monopoles and dyons in the Earth), DFUB 98/1 (1998), Astrop. Phys. 9 (1998) 173.

J. Derkaoui et al. (Energy losses of magnetic monopoles and dyons in scintillators, streamer tubes and nuclear track detectors), DFUB 98/13, submitted to Astrop. Phys. (1998).

[13] S. Nakamura et al. (A new limit on the flux of strange matter), Phys. Lett. B263 (1991) 529.

[14] G. Wilk and Z. Wlodarczyk (Propagation of Strange Quark Matter in the Atmosphere), presented at Strangeness'96 Workshop, Budapest 1996, hep-ph/9606401 (1996).

[15] C. M. G. Lattes et al. (Hadronic interactions of high-energy cosmic ray observed by emulsion chambers), Phys. Rep. 65 (1980) 151; A. S. Borisov et al. (Superhigh-energy cosmic ray interactions observed in emulsion chambers at Pamir and mt. Chacaltaya), Phys. Lett. B190 (1987) 226.

[16] G. Wilk and Z. Wlodarczyk (Centauro as Probe of Deeply Penetrating Component in Cosmic Rays), presented at IXth Int. Symp. on Very High Energy Cosmic Rays, Karlsruhe, 1996 and hep-ph/9609228 (1996)

[17] G. Wilk and Z. Wlodarczyk (How can strange quark matter occur deeply in the atmosphere?), hep-ph/9603228 (1996).

[18] M. Ambrosio et al., MACRO Coll. (MACRO limits for $g = g_D$ magnetic monopoles), MACRO/PUB 96/2 (1996); (Magnetic monopole search with the MACRO detector at Gran Sasso), Phys. Lett. B486 (1997) 249; (Magnetic monopole search with the MACRO detector at Gran Sasso), INFN/AE-97/19 (1997), in Proc. of the 25th ICRC, Durban, vol. 7 (1997) 157; F. Cei, for the MACRO Coll. (Search for rare particles with the MACRO detector), High Energy Physics Int. Conf., Vancouver, Canada (1998).

[19] G. Giacomelli, (MACRO Status Report), LNGS 1998 Annual Report; (1998); M. Ambrosio et al., MACRO Coll., (Nuclearite search with the MACRO detector at Gran Sasso) hep-ex/9904031, EPJ C (in press) (1999); see also Proc. of the 26th ICRC, Salt Lake City, vol. 2 (1999) 5; 112; 168; 172; 213; 277; 332.

[20] G. Giacomelli et al. (Extended calibration of a CR39 nuclear track detector with 158 AGeV Pb^{207} ions), Nucl. Instr. Meths. A411 (1998) 41.

[21] S. Cecchini et al. (Calibration with Relativistic and Low Velocity Ions of a CR39 Nuclear Track Detector), Nuovo Cimento 109 (1996) 1119.

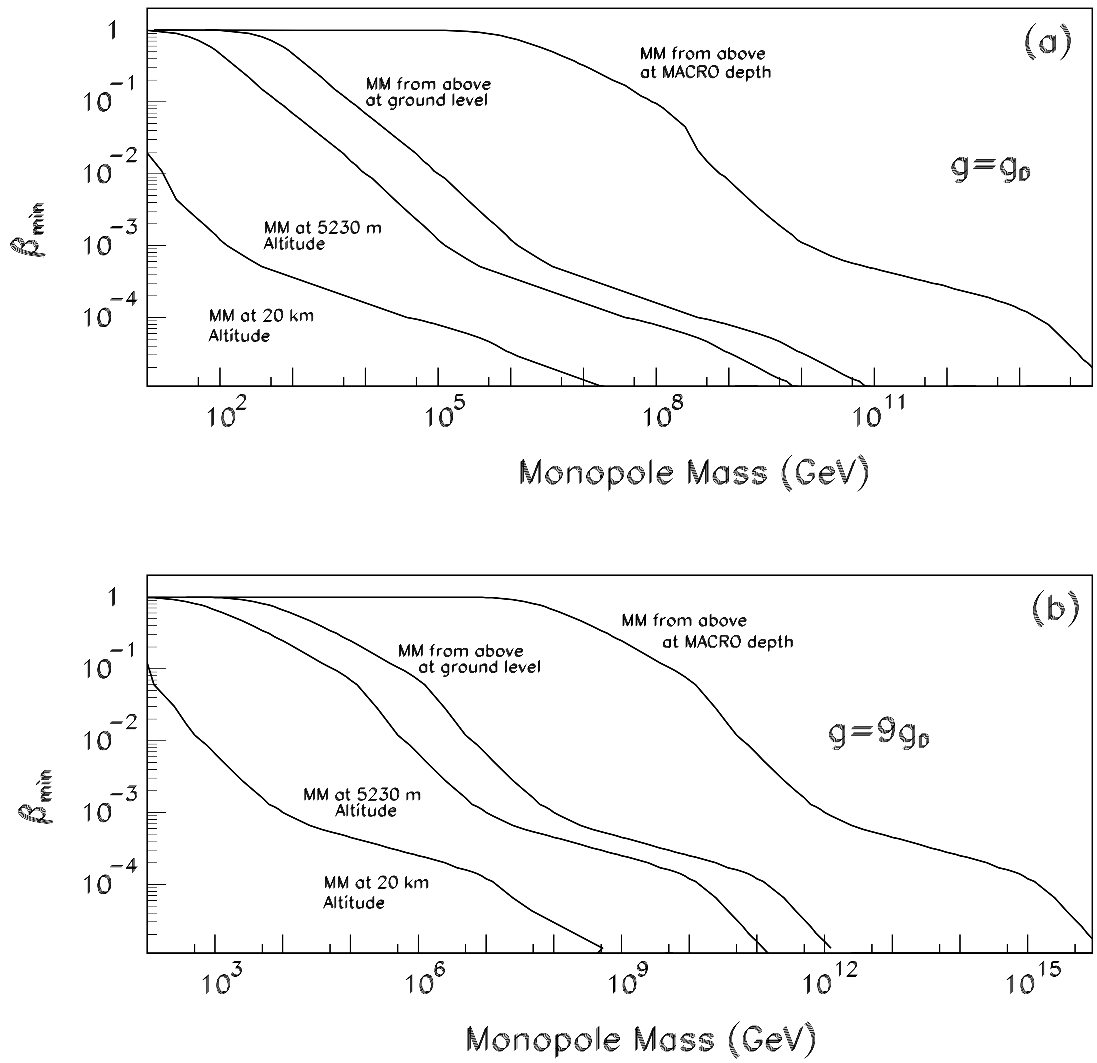

Figure 1: Accessible regions in the plane (mass, β) for monopoles with magnetic charge (a) $g = g_D$ and (b) $g = \ 9g_D$ coming from above for an experiment at altitudes of 20000 m, 5230 m, at sea level and for an underground detector at the Gran Sasso Lab. (like the MACRO detector). It is assumed that monopoles interact only via the electromagnetic interaction, and no radiative effects are considered [9]. If a light monopole attaches a nucleon or if it has some strong interaction, it could interact in the higher atmosphere, like primary protons and nuclei of the cosmic radiation.

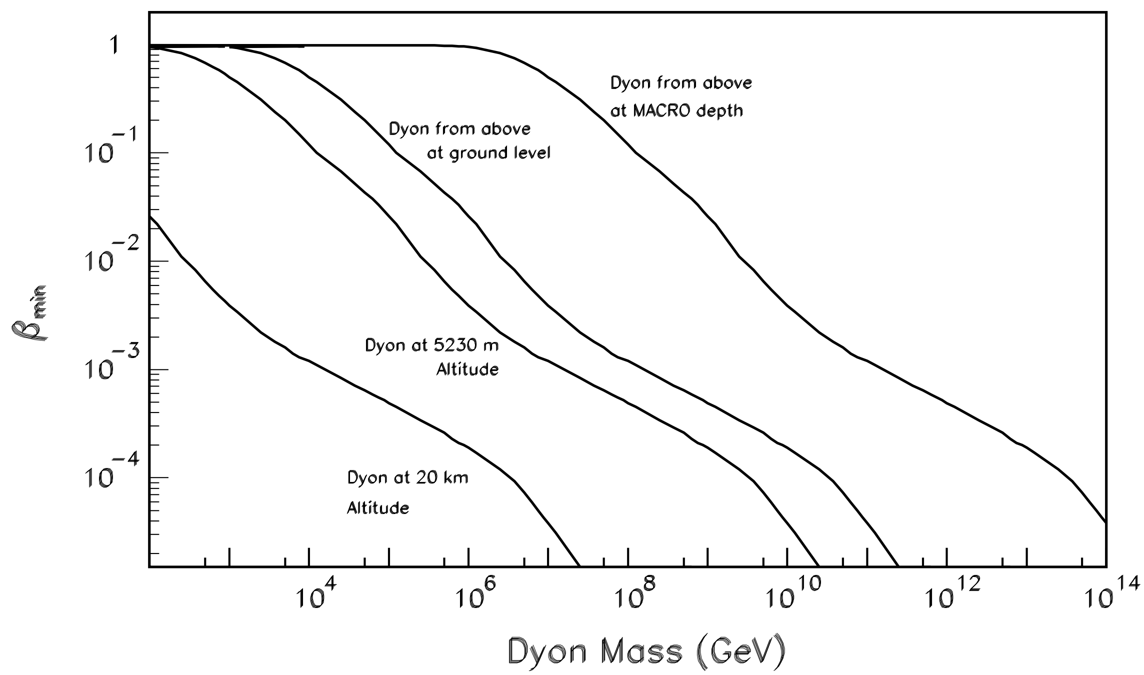

Figure 2: Accessible region in the plane (mass, β) for dyons from above for an experiment at altitudes of 20000 m, 5230 m, at sea level and for an underground detector at the Gran Sasso Lab. It is assumed that dyons interact only via the electromagnetic interaction, and no radiative effects are considered [9]. A monopole-proton composite would behave like a dyon with the addition of a strong interaction cross section, which may make it to interact in the higher atmosphere like primary protons and nuclei of the cosmic radiation.

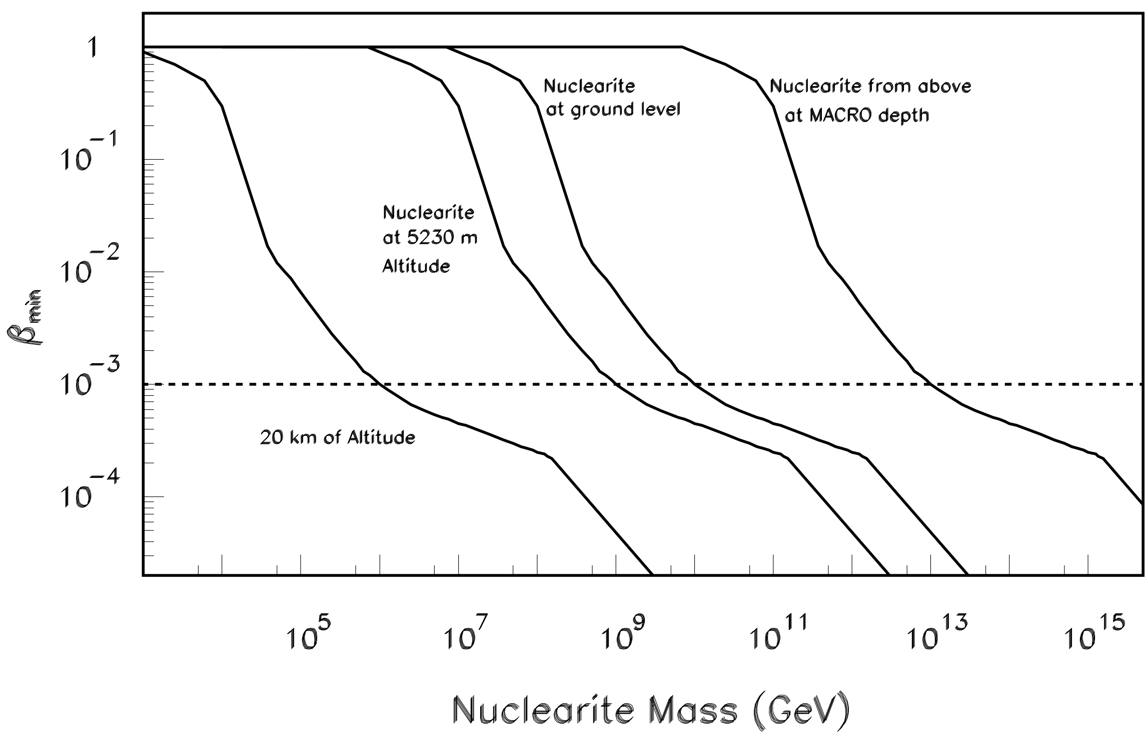

Figure 3: Accessible region in the plane (mass, β) for nuclearites. Only the energy losses via electromagnetic interaction are considered (bremsstrahlung is not considered). If nuclearites are part of the Dark Matter they would have typical velocities of $\beta \sim 10^{-3}$. It is highly probable that low mass nuclearites interact strongly; thus they may not reach the lower atmosphere.